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Forest structure of long-term conserved areas utilizing different strategies on a continental, glacial moraine formed island

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Forest structure of long-term conserved areas utilizing different strategies on a continental, glacial moraine formed island

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treatment, NP-NM = never planted, never mowed, previously farmed site, AP-NM = actively planted, never mowed, AP-M = actively planted, mowed). Letters indicate significant differences between treatments in the adult cohort (a>b) while shared letters indicate a lack of significance.

Figure 10-Average percent sand content found in each treatment (F=forested never farmed treatment, NP-NM = Never planted and never mowed, previously farmed site, AP-NM = Actively Planted and Never Mowed, AP-M = Actively Planted and Mowed). Error bars show standard error.

Figure 11- Relationship between basal area per ha (blue) and versus percent sand. (R^2=0.21,p=0.86), and Stem density per ha against present stand (in gray) (R^2=0.46,p=3.35).

Abstract

Understanding patterns of forest succession can help advise management plans within New England nature preserves. This study took place on Block Island, 13 miles off the coast of Rhode Island. The island has greater than 200+ years of farming practices. After 1960, conservation groups began reforesting the island using different strategies, such as actively planting with native and exotic tree species, mowing, and preventing further development. In 2018, woody vegetation was inventoried along transects within four reforested sites. Sites were characterized as the following: actively planted with exotic and native tree species and mowed (AP-M), actively planted with exotic and native species with no mowing (AP-NM), passively managed (no planting or mowing) (NP-NM), and never deforested (F). Trees (>5 cm DBH) were measured and identified within 10m of four 20m transects at each site. Saplings or shrubs (< 5cm DBH, > 1 m in height) were counted and identified within 5m of each transect. Tree seedlings (10 cm to 1 m in height) were counted and identified within 1m of each transect. Soil samples were taken every 20m along each transect and analyzed in a soil particle analyzer to determine soil texture. Reforestation strategy had a significant effect on adult tree basal area and diversity (p-value < 0.001). AP-NM had a significantly greater basal area (38.06 m2/ha) compared to "NP-NM" (13.14 m2/ha). The greatest richness of tree species was also found at "NP-NM" (5 species) while the lowest diversity was at "AP-M", which was represented by one species (*Prunus serotina*). Overall, seedlings were rarely encountered, but the greatest number of seedlings (660 individuals per ha) was found at "NP-NM", most of which were shadbush (*Amelanchier canadensis*). Soil texture was found to have no significant effect upon canopy but showed trends toward increased basal area and stem density with increased sand content. In conclusion, "AP-NM" significantly increased the diversity and basal area but had no effect on seedling recruitment in the understory. This is most likely due to the overpopulation of deer on the island.

Introduction

The resilience, or ability of temperate forest ecosystem to recover from deforestation, after agricultural abandonment, is understudied on isolated, continental islands of the Eastern United States. Understanding barriers to forest succession has implications for conservation and restoration practices on these often small and vulnerable ecosystems.

New England has a history of extensive agriculture, which changed the forest composition of the region in the 1800's. When these agricultural lands were abandoned in the post-World War II era many farms were allowed to naturally regenerate back to forest (Fuller et al., 1998). Block Island, located off the coast of Rhode Island, followed these trends of agriculture and abandonment, but the forest recovery has been slow. Now many areas on Block Island, which were previously farmed, are conserved for tourism and recreation and the protection of several federal and state endangered and threatened species (Hammond, 1998). Block Island, along with other islands of the coast of the Eastern United States, are also increasingly popular vacation destinations. The same isolation, which for decades, protected the ecosystems of these islands from development, now makes them more appealing for second homes. Block Island was largely spared land conversion for development until recently due to its smaller size and isolation. In addition, several non-profits have purchased or put into easement approximately 1158 hectares (representing approximately 44.7% of land) on Block Island, protecting the land from further development. Located 9.8 miles off the coast of Rhode Island, it is considered to be a biodiversity hotspot of Rhode Island and New England (Littlefield et al., 1998) (Figure 1). While the island is far from undisturbed, the anthropogenic landscape remains a refuge for endangered species such as the American burying beetle (*Nicrophorous americanus*), piping plover (*Charadrius melodus*) and northern blazing star (*Liatris scariosa)* (Littlefield, 2002; Enser, 1998). The small island's year-round community of approximately one thousand people, and summer residents are active in conservation efforts to protect the island's endangered species, sole source aquifer, coastal dunes and beaches (Littlefield, 2002).

Like the other islands in New England, the resilience of oak/hickory stands on Block Island after agricultural abandonment is largely unknown. Island forests have been heavily harvested since colonial times (Hammond, 1998). Block Island's historically oak/hickory dominated hardwood forests were almost completely removed for building materials, fuel, and farmland (Hammond, 1998). The agriculturally dominated landscape was mostly abandoned in the 1950's and has since transitioned into another stable state described as a coastal shrubland (Hammond, 1998). This ecosystem is low in vegetative diversity with a high stem density and few other species can regenerate beneath its canopy (Hammond, 1998).

As the island's tourist industry became more popular in the 1960s, recreation became a more suitable use for land. Conservation of the limited wood and freshwater resources became a priority of the island community. Some landowners and property managers in the 1970's planted extensive rows of trees, usually exotic, in an effort restore tree cover to the island (Hammond, 1998). The most common exotic trees planted were two evergreen species – the Japanese black pine (*Pinus thunbergii*) and Norway spruce (*Picea abies*). These species were most likely selected because their dense canopy was thought to be effective in suppressing the invasion of coastal shrubland while encouraging regeneration of native species beneath its canopy. Many stakeholders on the island are interested in the regeneration of native tree species because they are concerned about water resources, tourism, bird populations, endangered species (Veeger, 2002; Hammond, 1998; McDermott, 2009; Littlefield, 2002).

History of Acute Disturbance on Block Island

The removal of native trees by plowing, and the harvest of lumber and peat resulted in a landscape unable to regenerate from stump sprouting or residual seed banks. The few areas that were able to regenerate from stump sprouting or seed banks are limited by other factors, such as competition from shrubs (e.g. *Amelanchier spp.; Rosa multiflora)* and poor soil conditions (Hammond,1998). A specific swampy areas of the island escaped agricultural use and peat harvest, which resulted in a stump-regenerating cohort of black gum (*Nyssa sylvatica)*, red maple (*Acer rubrum)*, and American beech (*Fagus grandifolia)*. These forest fragments are a potential source of seeds and animal seed-dispersers (Hammond, 1998).

Typically, after land was abandoned on the mainland, early pioneer species such as black cherry (*Prunus serotina)* would colonize the land and outcompete shrub species (Niering and Goodwin, 1974; Starfinger, 1991). Years later, pioneer species would establish a canopy, thin their density, and facilitate the succession to mid successional species such as *Quercus spp*. and C*arya spp*. (an oak/hickory forest) as has been seen in mainland New England (Fuller et al., 1998; Kozlowski, 2002; Starfinger, 1991). However, on the island, the predicted successional pathway is different because of poor diversity of trees and lack of animal seed dispersers. Early pioneer species present on the island are black cherry*,* Black locust *(Robinia pseudoacacia)* and Shadbush (*Amelanchier canadensis)* and mid successional species present on the island are American beech*,* Spanish swamp oak *(Quercus palustris)* and black gum *(*Hammond , 1998*).* However, these are not the most common species found on the island. Instead the island has transitioned to a coastal shrubland dominated by shadbush*.*

The coastal shrubs (e.g., shadbush) would normally be limited to the salty spray zones by forest overstory light competition. Salinity in those areas would limit the growth of the less salt tolerant tree species found in the forest. This would leave the shrubs as fringe species between coastal grasslands/dunes and the dense oak/hickory forests (Jolly, 1993; Hammond, 1998; Kozlowski, 2002). However, the coastal shrubland moved inland after agricultural abandonment of the previously forested areas (Hammond, 1998). In dense, well-established shrubland ecosystems, tree seedlings cannot compete for below or above ground resources particularly after 10-12 years of shrubland growth (Niering and Goodwin, 1974; Putz and Canham, 1992). The shrubland on Block Island is now many decades old and has formed a low, dense canopy.

Black cherry, although considered a light-demanding species, is one of the few tree species that has been able to emerge through the shrub layer. This species is also a pioneer, generalist species with the ability to colonize many different kinds of habitat *(*Auclair and Cottam, 1971). Black cherry is bird-dispersed and the coastal shrub ecosystem dominated by shadbush attracts birds during the fruiting season. Wind disturbance may also open up sufficient light in the shrub canopy, allowing black cherry to surpass the shrub layer. The success of black cherry may also be dependent on soil texture and the retention of nutrients and moisture (Niering and Goodwin, 1974; Hammond, 1998).

Lack of propagules, besides black cherry, presents a major barrier to natural regeneration. The island's initial colonization of forest trees predated the formation of the island, and long-distance colonization events are uncommon (Jacquemyn et al., 2003). Therefore, remnant island trees or trees planted by humans are the main source of propagules (Jacquemyn et al., 2001). Established island trees, which could serve as seed sources, are a mix of native and exotic species. Exotic evergreen species, such as Japanese black pine (*Pinus thunbergii)* and Norway spruce (*Picea abies)*, can serve as nurse trees and, facilitate the regeneration of more shade tolerant native trees species in the understory (Reay, 1999). Deciduous species planted on the island, such as sugar maple (*Acer sacc*har*um)*, can also facilitate understory tree establishment in areas with more moisture due to a high tolerance for climate fluctuations (Hett and Loucks, 1971). Other native species, such as American beech*,* Spanish swamp oak*,* and black gum*,* are present on the island and if their seed was to disperse we would expect to see them establish under such canopies. The first protected areas were established on Block Island in the 1970s. Given the long timescale of forest succession, we would expect it to take time for forests to establish in these areas. Active reforestation strategies used was either planting trees or planting trees and mowing (Hammond, 1998). Passive reforestation, allowing the land to rely on naturally regenerate, was also practiced. The forests resulting from these three reforestation practices are described below from data collected by Hammond in the 1998 or the Block Island Conservancy in 1996. Areas conserved early on in the island's history of conservation provide a longer-term view of the effects of these conservation practices. Four long-term conserved sites are identified as having the following practices implemented.

1) Intensive Active Reforestation with Planting and Mowing (AP-M): This land was planted with trees starting in 1975, and mowed initially to suppress shrub growth and limit competition. This stand was dominated by Spanish swamp oak, black gum, and black locust (Hammond, 1998). Japanese black pine was also planted and formed a dense canopy, but the turpentine beetles killed the trees in the mid-1990s. This die-off created large gaps that were colonized by black cherry in the drier areas and red maple and black gum in the wetter areas (Hammond, 1998).

2) Moderate Active Reforestation with Planting (AP-NM): This stand was first planted with Norway spruce, Japanese chestnut (*Castenea crenata*) and sugar maple in 1945.

3) Passive Reforestation (NP-NM): This land was left to regenerate without intervention. Agriculture in this area was ceased in 1972. This stand was dominated by shrub species including Shadbush and multiflora rose (*Rosa multiflora)* in 1998. Black Cherry was also starting to emerge through the shrubs twenty years ago (Hammond, 1998).

One area of the island, known as the "The Great Swamp", can serve as a reference point for what forest composition was historically in hydric soils. This area was logged but never converted to crop agriculture. Black gum and American beech dominate the forest canopy with sassafras (*Sassafras albidium*) and scattered oaks (*Quercus spp.)* (Hammond, 1998). All of these species are animal dispersed and could be a source of propagules for regenerating forests on the island. Black gum is especially adapted for wet soils as their seeds can remain dormant while submerged in water for several weeks, and can quickly germinate when more ideal conditions are met (Debell, 1972; Hammond, 1998).

Rationale for this Study

While a floristic survey of planted sites on the island was conducted twenty years ago (Hammond, 1998), there was no comparative analysis of tree regeneration within the three different restoration sites. Understanding which reforestation strategy was most successful in facilitating native tree regeneration will help inform future restoration plans.

I hypothesized that:

1) If reforestation strategy has an effect upon forest canopy, then differences in stem density, basal area and species richness will be seen in different treatments.

2) If reforestation strategy has an effect upon shrubby species density in the canopy, then shrubby species density will be found different in different treatments.

3) If reforestation strategy (management treatment) has an effect on abundance and species richness of tree regeneration, then we will see differences in seedling and sapling species richness and density in the understory of these treatments. The most intensive treatment (AP-AM) was predicted to have the greatest abundance and number of species in the regeneration layer.

4) If soil texture has an effect on forest structure, then we will see differences in forest structure in areas with different amounts of sand. Sand content was predicted to change composition should the sand content be found different between sites.

To test these hypotheses, objectives of this study were as follows:

1) Describe the forest canopy in terms of stem density, species richness, basal area and carbon in the reforestation sites and the historic remnant forest.

2) Compare abundance of coastal shrub species in the different reforestation sites.

3) Identify the density and species richness of natural regeneration of tree species in the understory in the reforestation sites and the historic remnant forest.

4) Determine the relationship between soil texture (% sand) and forest structure (density and basal area).

Methods

Site Description

Topography, geology, climate of Block Island

The island's glacial formation, whose last deposition was approximately 25,000 years ago, created different soil types and deposits; the most common of which are ablation till, lodgment till, and fluvial deposits settled on a bedrock at least 300m below the surface (Boothroyd and Sirkin, 2002; Rozenweig, 2002). The island was isolated by sea level rise with the draining of a glacial lake approximately 15,000 years ago (Boothroyd and Sirkin, 2002). Clayey soils from the Montauk drift support the water table on Block Island. Areas where the Montauk soils are present are swampy and often saturated with water and can be submerged under small ponds or forested or shrubby swamplands (Boothroyd and Sirkin, 2002). The lowest dry area on the island is a glacial outwash basin, whereas the highest elevation areas (Beacon Hill or Corn Neck region) are recessional moraines of poorly sorted sediments. The landscape of the island includes rolling hills with approximately 500m of relief between hillcrests; and many small ponds are scattered across the landscape (Rozenweig, 2002).

The Island's climate is moderated by the surrounding ocean and holds an average high temperature of 15°C (59°F) and an average low of 7°C (44°F). The average annual precipitation on Block Island is approximately 108 cm (42.6 in) (Rosenweig, 2002; NOAA, 2013).

Great Swamp (41° 9' 59.0328'' N, 71° 35' 19.446'' W), Rodman's Hollow (41° 9' 29.3328'' N, 71° 35' 19.446'' W), Nathan Mott Park (41° 10' 10.2828'' N, 71° 35' 20.0508'' W), and the Lapham property (41° 13' 0.7032'' N, 71° 33' 29.916'' W) were the locations used for this study (Figure 3). All four locations were selectively harvested for timber and used for pasture or agriculture until the 1960s with the exception of Nathan Mott Park which was founded as a recreational park in 1941. Great Swamp, Rodman's Hollow, and Nathan-Mott Park are located on the south end of the island while the Lapham property is located on the northern end of the island.

Great Swamp (13.76 hectares) is unique from the other three locations in that plowing never occurred and remnant tree stumps were left behind. This site was converted to pasture instead of agricultural fields because of the swampy conditions. The dominant soil series in this site is the Ridgebury series, an entisol. However in some higher slopes, the Woodbridge series, an inceptisol is most common. As the sampled area is an isolated hill in the middle of the swamp, the Ridgebury series is the expected soil series (Soil Survey Staff, 2019). This area is defined as never deforested (F) in this study, as trees were allowed to regenerate from rootstocks. Great Swamp has been protected from development because it serves as the island's primary water source and is owned by the Boy Scouts of America.

Rodman's Hollow (93.1 hectares) is a glacial outwash basin, which was purchased by the The Block Island Conservancy group in 1972. The dominant soil series in this site are the Gloucester series, an inceptisol, on hillsides and peaks and the Hinckley series, an entisol in depressions (Soil Survey Staff, 2019). Samples were taken from the base and upper slopes of the glacial depression. Other than maintaining trails for recreational practices, including horseback riding and hiking, this area was not actively restored and was left to regenerate naturally. This area is defined as passively managed as it was not planted or mowed (NP-NM).

Nathan Mott Park (16.0 hectares) was donated to be the island's first park and was planted with native and exotic trees starting in 1945. The dominant soil series in this site is the Gloucester series, an inceptisol, this is most common on hills and slopes and as the sampled area is on a hillside this supports the Gloucester series being the sampled soil series (Soil Survey Staff, 2019). The park is heterogeneous in terms of management with several practices in different areas. A large area (approximately 28.5 of the original 68 acre property) was thinned to provide clearance for the island's nearby airport. The property is dominated by three habitat types: maritime shrubland, grassland, and coniferous forest. This smallest area, particularly a steep slope in the northeast corner of the property, was planted with sugar maple, Norway spruce, white pine, red pine (*Pinus resinosa*), and larch (*Larix sp.*). Norway spruce and sugar maple remain in the canopy today. The majority of the park was planted with sugar maple and Norway spruce species remaining in the canopy. Sampling was restricted to areas not dominated by Norway spruce as there were only a small area left with a Norway spruce canopy. The remaining area is dominated by deciduous species. This site was defined for this study as actively planted and not mowed (AP-NM).

The Lapham Property (36.4 hectares) is a large conservation easement site conserved by the Lapham family since 1965. This area is a collection of rolling hills. The dominant soil series in this site is the Hinckley series, an entisol (Soil Survey Staff, 2019). The Lapham property was planted with a mix of tree species in 1965 and mowed initially to suppress shrubs and encourage tree regeneration. The areas focused on in this study were planted with Japanese black pine with the intention of suppressing shrub species. The pine canopy died after the accidental introduction of the turpentine beetle (*Dendroctonus terebrans*) to the island in the early 1990s. This area was defined as actively planted and mowed (AP-M).

Study Design

The abundance and species richness of seedlings, saplings and adult tree species as well as shrub species were surveyed using randomly placed transects, perpendicular to hiking trails within three of the four sites. The isolated hill within the great swamp did not have a trail system and consequently, three 20m transects were randomly placed at least 20m apart.

At the sites with established trail systems, numbered points were placed in trails through each treatment at least 20m apart, a random number generator was used to select which points were used to place transects. The side of the trail the transect was run from, and the side of the transect the data was collected from were both selected randomly.

Three study sites had at least 4 transects while the Great Swamp site only had 3 transects due to the small size of the treatment area (Figure 3). Adult trees and shrubs that were greater than 5 cm DBH were identified, DBH measured, and counted within 10 meters of the transect. Tree saplings and shrubs less than 5 cm but greater than 1 m in height were identified and counted within 5m of the transect. Tree seedlings or shrubs that were between 10cm and 1m in height were identified and counted within 1m of the transect.

Soil Survey

Soil was collected at the beginning and end of each 20 m transect using an 8cm diameter soil augur to the depth of the second soil horizon. A soil sample was collected from each soil horizon. Soil texture was quantified from these samples.

Soil texture analysis was performed using a Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer with an Aqueous Liquid Module. Samples were prepped by sieving each sample through a 2mm sieve and drying at 105 degrees Celsius for 24 hours. One gram of each soil sample was then added to 50 mL of 5% hexametaphosphate solution similar to other studies (Eshel, 2004). The Fraunhofer model was used to calculate particle size.

The percent of particle size for sand, silt, and clay was calculated from the systems analysis software. The systems software provides relative masses of the different particle sizes. Percent of each particle size was calculated by adding up percentages of each particle size within the ranges of each particle size (clay particles are less than .002 mm silt are between .002mm and .06mm and sand are between .002mm and 2mm).

Data Analysis

Woody species richness and abundance in each cohort (adult, sapling, seedling) was quantified for each transect at each site (4 treatments). Percentage of shrubby species in the canopy, total basal area and total carbon stored were also determined for the adult cohort. Carbon was calculated using methods outlined by Mcpherson and Doom (2016) for calculating carbon with DBH measurements without height measurements.

An Analysis of Variance was used in R (version 3.4.3) with a Tukey-Kramer post-hoc on each dependent variable that had normal distributions with equal variances. This was determined by the

Shapiro-Wilks and Levene test. Non-normal data but with equal variances were analyzed with the Kruskal Wallis test followed by a Dunn's test for multiple comparisons post-hoc test. A regression was performed on percent sand and stem density and basal area to determine relationships between soil sand content and forest structure.

Results

Tree/shrub canopy and subcanopy

The first objective to describe the forest canopy shows that the tree/shrub canopy (individuals > 5 cm DBH) was significantly affected by site. Stem density was greatest in the two reference sites (forest - "F" and never planted/never mowed - "NP-NM") and were significantly different from the two managed sites (actively planted/never mowed - "AP-NM", actively planted/mowed - "AP-M") (H = 10.11, p =0.017) (Figure 4, Figure 5). Stem density ranged from 788 stems per ha in the "AP-NM" to 2150 stems per ha in the "F" treatment. Basal area was significantly greater in the reference site "F" and the managed, planted site "AP-NM" compared to "NP-NM" and "AP-M" (H =11.84 , p =0.010; Figure 6). Basal area per ha ranged from 5.15 to 68.33 m^2 (Figure 6). Species richness was significantly greater in "AP-NM" and "NP-NM" compared to "AP-M" (H = 8.65, p =0.034; Figure 7). The greatest number of species found was 5 species in "NP-NM" treatment. Dominant species in the reference sites were shadbush, a shrubby species, in "NP-NM" and black gum in F. More actively managed sites were dominated by black cherry in "AP-M" and Japanese chestnut (planted) in "AP-NM". Black cherry was found in all treatments except "F" and shadbush was found in all treatments except "AP-M" (Table 1). Carbon stored was found to be significantly different between treatments (*H*=10.03, *p*= 0.02). Greatest average stored carbon was found in treatment "F" (167.38 t/Ha) followed by "AP-NM" (146.85 t/Ha), "NP-NM "(40.58 t/Ha), and "AP-M" (32.15 t/Ha) respectively (Figure 8).

Canopy structure is significantly affected by treatment, including basal area, stem density, species richness, and carbon stored. Treatment effects of planting and mowing appear to reduce species richness and stem density, while planting appears to increase basal area and carbon storage in the “AP-NM” treatment to be more similar to the natural rootstock forest fragment “F”.

Shrubby species stem density

The objective to survey and compare the shrubby species density showed a difference between treatments. The density of shrubby species (mainly shadbush) was found to be significantly higher in the reference site “NP-NM site” than all other sites with 1670 stems per ha (Figure 5, Figure9). It should also be noted that no shrubby species were found in the adult cohort of treatment “AP-M” though it is not significantly less than treatments “F” or “AP-NM” (Figure 9).

All methods of suppressing shrubby species appear to be affective as the “NP-NM” treatment has significantly greater shrubby species than either actively managed treatment. The natural canopy treatment “F” had more shrubby species on the edge of the habitat indicating that the shrubby species are likely edge habitat species.

Woody species regeneration

Overall, regeneration was not significantly different between sites. Site treatments did not have a significant effect on seedling density because of high variation between transects (H=4.13, p=0.24). Seedling density was greater in the two reference sites with the highest number found in “NP-NM” with 6600 seedlings per ha followed by “AP-NM” with 2652 seedlings per ha. “AP-M” had fewer seedlings with 125 seedlings per ha and “F” had an average of 3000 seedlings per ha (Figure 4). “AP-M” had very poor regeneration with only one seedling found in all four transects. However, Site treatment also had no significant effect on sapling density (H=3.15, p=0.36) (Figure 4). Sapling density (individuals < 5 cm in

DBH) was greatest in “NP-NM” with 4440 saplings per ha, followed by “F” (2080 saplings per ha), “AP-M” (2200 per ha), and “AP-NM” (1025 saplings per ha). Species richness of seedlings and saplings was not significantly different between sites (H=3.16, p=0.36; H=6.10, p=0.10) (Figure 7). The highest species richness of seedlings was found in “NP-NM” (4 species) followed by “AP-NM” (3 species), “F” (2 species), and “AP-M” (1 species). Sapling species richness was greatest in “NP-NM” with seven species followed by “AP-NM” (4), F (3), and “AP-AM” (1).

Regeneration of woody species appears to vary greatly across treatments however these differences were not found to be significant in density or species richness. Both species richness and seedling/sapling density are low with the highest richness being 7 species total in the understory and the lowest being 1.

Soil

Soil texture was not significantly different between treatments (H=6.8221, p=0.07). However, the F site had the highest average percent of sand while the AP-NM site had the highest percent of clay (Figure 10). Forest structure showed trends with an increasing density of trees and basal area with an increase in percent sand but these relationships were not significant (Figure 11).

Soil texture did show some differences between treatments; however, in this case it appears that sand content is not a driving factor in regeneration. It should be noted that the treatment with the highest sand content also holds the highest stem density and basal area of all treatments (treatment “F”) (Figure 10).

Discussion

Deforestation, or the removal of trees from a landscape, is a common occurrence across the Eastern United States, often to establish agricultural land. Reforestation of these areas occurs though succession as their agricultural practices are abandoned. Depending upon management practices and nearby seed sources, reforestation can follow different successional pathways.

The secondary forest canopy differed across Block Island depending on whether the site had been actively or passively restored fifty years ago. Intensively managed sites were planted with trees and mowed periodically. Less intensively managed sites were allowed to passively regenerate, relying on the natural capital of the landscape. Forest structure, quantified by species richness, density, basal area, and carbon storage, all differed between sites. Stem density was significantly higher at the sites that were allowed to naturally regenerate (NP-NM, F), than in sites that were just planted or planted and mowed for suppression of shrubby species (AP-NM, AP-M). Plantations usually have a regular pattern of spacing (~ 6 meters between trees), while naturally regenerated systems is more random, depending on distance from a seed source and mode of dispersal (Jacquemyn et al., 2003). In addition, stump sprouting resulted in higher stem density (2150 per ha) in the forested site (F), compared to the two managed sites which had less than 421 stems per ha. Regeneration from stump sprouts left in abandoned fields has been noted to be the main source of regeneration after agriculture (Braun, 1950; Elger, 1954). *Nyssa sylvatica* and *Fagus grandifolia,* commonly found at the forested site*,* both regenerate from stumps readily (Kozlowski et al., 1991). These individuals contributed to a greater basal area per ha and carbon per ha found in the forested site.

However, species richness was poor at all sites ranging from one to seven species in the canopy/subcanopy. This could be due to limited seed sources in post-agricultural transitions or heavy deer herbivory in the initial stages of succession. Although the passively regenerated site (NP-NM) had the most number of species (7), the majority of individuals of > 5 cm DBH were shadbush, a shrubby, many-stemmed species, dispersed by birds. Shadbush is an early successional species that does well in high-light conditions and can out-compete native species due to its fast growth rate and tolerance of a range of conditions. Black cherry, appears to be an important step in succession as it regenerates underneath this dense canopy (Niering and Goodwin, 1974). Other less commonly encountered species, such as Bayberry (*Myrica pensylvanica*) and Arrowood (*Viburnum dentatum*), were also classified as shrubs. Trees, such as *Quercus spp.* and *Carya spp*., were notably absent. This is striking considering that the forested ecosystem on the islands was historically classified as an oak/hickory forest in drier areas and blackgum/beech/maple forests in wetter areas. Although shadbush*,* is an important source of food and provides resting sites for migrant birds (Reinert et al., 1998), the lack of diversity has other implications, such as decreased resources for birds outside of the season in which they fruit, and vulnerability to invasive species such as tree of heaven (*Ailanthus altisima),* which is present on the island and is known to grow quickly after minor disturbances (Hu, 1979).

The planted site that was not mowed was dominated by Japanese chestnut while the planted and mowed site was dominated by black cherry. This mix of native and non-native species provide habitat and resources for wildlife and provide ecosystem services including carbon sequestration, soil conservation, and water purification. These species also limited the density of shadbush and facilitated the regeneration of black cherry. Nursery or plantation trees are often used to facilitate the regeneration of desirable species (Dey et al., 2012). Mowing and planting conifers (AP-M) does could decrease the density of shadbush as no specimens were found in this treatment (Figure 8). Other studies have used mowing to suppress undesirable species such as Huckleberry *(Gaylussacia baccata)* and bearberry *(Arctostaphulow uva-ursi)* in Nantucket (Zuckerberg and Vickery, 2006).

The canopy/subcanopy may help explain patterns found in the regenerating layer of the understory. Understanding what is happening in the regenerating layer is critical to the future structure of the canopy. Given the dominance and fast-growth of shadbush in “NP-NM” sites, we predicted a dominance of this species regenerating as well. We also predicted that shade tolerant tree species, black gum and American beech, would be regenerating in the understory of the forested site. Overall, seedling density was very low with the greatest number of seedlings, mostly shrubby species

(*Amelanchier spp*., *Myrica spp*.), found at “NP-NM” site and the least found at “AP-NM” site. This can be explained by low light levels, especially under the canopy of chestnuts *(Castenea sp.) and* sycamore maple *(Acer pseudoplatanoides)* in the “AP-NM” site and deer herbivory at all sites. Deer (*Odocoileus virginianus)* are known to be largely responsible for a decline in oak regeneration (Wakeland and Swihart, 2009) and other species such as pin cherry and sugar maple (Marquis, 1974). The island has very high deer browse pressure and any management plan including tree plantings or natural regeneration should consider the impact of deer herbivory (Niering and Goodwin, 1974; Hammond, 1998).

Soil sand content was not found to be significantly different across our treatments (Figure 10); however, there are trends (though also not significant) seen for an increase in basal area and stem density with increasing sand content (Figure 11). This is likely driven by the “F” treatment having the highest sand content while simultaneously having high numbers for stem density and basal area. This leads me to believe that management and propagule availability are driving the relationships seen in this study more than relationships of soil characteristics. While soil should be considered in a management plan, more information may be necessary to make any conclusions on the effects of soil on these sites.

Conclusions

The information from this study could be used differently depending upon the priorities for particular tracks of land on the island. Enrichment of avian habitat for spring migrants is a high priority for conservationists on Block Island. This is an interesting paradox because *Amelanchier canadensis,* the most prevalent shrub species in the ecosystem that suppresses tree regeneration, provides both fruit and nesting habitat for migrating avian species. However, avian habitat, must be balanced with other ecosystem services such as soil and water conservation and carbon sequestration.

Species richness, which will improve ecosystem resilience (and thereby soil and water conservation), can be increased by enrichment plantings in the understory of tree canopies. Planting native species such as *Quercus spp., Cary spp., Nyssa sylvatica* and *Fagus grandifolia* is recommended as they are either present in the island's canopy in other areas or are thought to have been part of the dominant forest type on the island historically (Hammond, 1998). To decrease the encroachment of the coastal shrubland, red pine (*Pinus resinosa*) is recommended to be planted as a nursery species. This species has been seen to promote the growth of mixed hardwood species and Japanese black pine decreases shrubs on the island (Parker et al., 2001; Hammond, 1998). If carbon sequestration is the main goal, fast-growing tree species with high wood densities, such as black locust (*Robinia pseudoacacia*), honey locust (*Glendista triacanthos*), are recommended. Seedlings should be protected from deer herbivory to prevent fatality from deer browse.

Further questions

A more extensive study into the dynamics of regeneration under *Amelanchier canadensis* would be beneficial. The passively managed site (NP-NM) had areas with little to no understory under dense *Amelanchier canadensis* canopy. *Amelanchier canadensis* are especially susceptible to wind disturbance and can often only form a lower shrubby habit, however on the island, in some more protected locations has been seen to reach heights up to 6m in height (Hammond, 1998). Comparing differences in *Amelanchier canadensis* forests in sheltered habitat versus unsheltered habitat (higher elevation) may help answer the questions of how best to manage the *Amelanchier canadensis* stands which are prevalent on the island. If an increase in *Amelanchier canadensis* is desired, then an area of higher wind may need to be more actively managed to prevent succession of black cherry which will shade out shadbush. However in a more sheltered area, as seen in the NP-NM site Rodman's Hollow, the succession to cherry canopy could be arrested due to the heavier canopy. Further study of these sites comparing age, basal area, carbon storage and fruit yield could be used to design an inverval of thinning to provide the most effective management for migratory bird resources.

Black cherry is the most common tree species on Block Island seen in this study. Comparing its value as an avian species resource to shadbush would be interesting to evaluate whether or not its succession can be suited to better serve the community as a resource. Black cherry is seen as an intermediate between the shrubby species (like shadbush) and tree species (Niering and Goodwin, 1974). The value of black cherry as a resource could serve a different service from shadbush as a resource for avian species as they have different size fruits and different fruiting seasons (Stiles, 1980). Quantifying the values of these species as wildlife resource providers could help provide a greater base of resources for management goals.

Black cherry dominated the planted/mowed site would be expected to succeeded by other hardwood species in future years with passive type of management despite the lack of other native species in the understory. Mid to late successional species, such as *Quercus* spp., are unlikely to regenerate underneath black cherry canopy because seed sources and seed dispersers are few. It is possible that the black cherry canopy would be the end result creating a stable state, much as seen with the shrubby species on the island, or could succeed to another present species on the island, such as remnant red maple, black gum or beech provided their seeds disperse to these areas (Niering and Goodwin, 1974; Hammond, 1998). However the species found at the seedling stage in the understory is tree of heaven, a known invasive species, and is a very likely successor to cherry in these areas. An underplanting of other native species could be utilized to control what species succeed in areas lacking in propagules. Black cherry is also susceptible to wind disturbance and gaps are likely to be filled with other species. Underplanting with other species would allow chosen species to take advantage of the gaps instead of undesirable species. Further study and monitoring to determine the trends of continuing succession is needed to fully understand future trends in this environment.

In order to continue and replicate the mostly stable state seen in the dense shrubby habitat seen in the NP-NM treatment and thereby increase avian bird habitat, the removal or control the *Prunus serotina*, and other encroaching woody species, from the habitat must be periodically performed to prevent over shading of shrubby species currently found in the canopy. The protection of preferred species should be a priority. Thinning of larger specimens of preferred species may be beneficial to overall enrichment for avian species by increasing overall complexity of the habitat. Continued monitoring of these sites to better understand the interactions of species found in these areas and the arrival of new species in these areas is critical for the longterm success of these restoration plans. Succession beyond desired species and competition from introduced invasive species are likely to become a bigger problem in the years to come. Early understanding of these trends can help property managers to be more prepared with countermeasures against threats to their management goals despite changes in the floral community which may arise.

Table 1. Number of individuals of each species found in the adult cohort (> 5 cm DBH) in each treatment (F=forested never farmed, NP-NM = never planted and never mowed, previously farmed site, AP-NM = actively planted, never Mowed, AP-M = actively planted, mowed), and growth form (Shrub or Tree).

Species	Common Name	Growth Form	F	NP-NM	AP-NM	AP-M
Amelanchier canadens	Shad	Shrub	14	135	4	0
Lonicera maackii	Honeysuckle	Shrub	0	14	0	0
Myrica pensylvanica	Bayberry	Shrub	0	2	0	0
Vibernum dentatum	Arrowood	Shrub	0	3	0	0
Prunus serotina	Cherry	Tree/Shrub	0	47	13	75
Acer pseudoplantanus	Sycamore Maple	Tree	0	0	9	0
Castenea crenata	Chestnut	Tree	0	0	37	0
Fagus grandifolia	Beech	Tree	4	0	0	0
Nyssa sylvatica	Tupelo	Tree	110	0	0	0

Figure 1. Block Island, located approximately 13 miles from mainland Rhode, Island.

Figure 2- A map of Block Island, Rhode Island. Marker 1 is Great Swamp, marker 2 is Rodman's Hollow, marker 3 is Nathan Mott Park, and marker 4 is the Lapham Property.

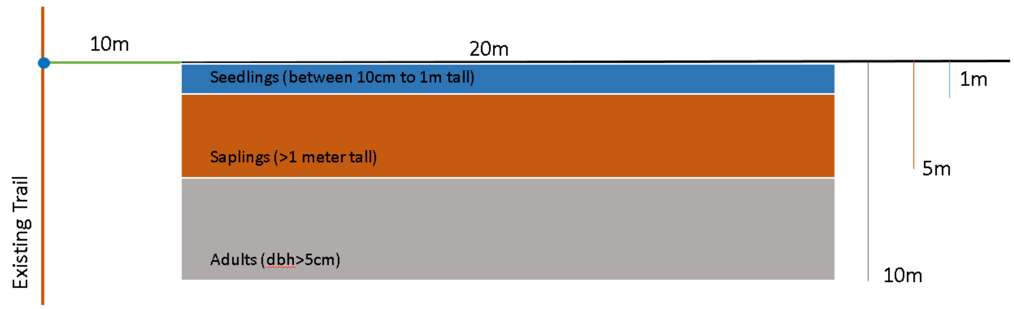

Figure 3-Design of how seedlings, saplings, and adult trees were sampled along each 20m long transect. Each transect began at least 10m from the existing path. Adult trees (those with a DBH greater them 5cm) which were within 10m of the transect were recorded. Saplings (those with less than 5cm DBH but greater than 1 meter in height) were recorded within 5m of the transect. Seedlings (plants between 10cm and 1m in height) were recorded within 1m of the transect.

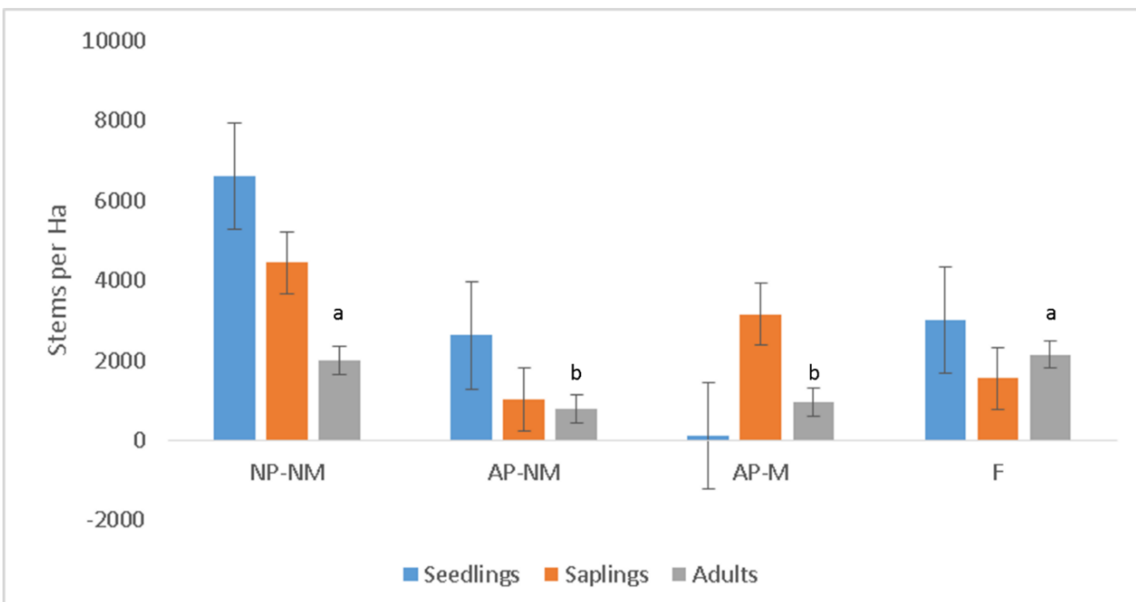

Figure 4 -Stems per Ha of each cohort for each treatment (F=forested never farmed treatment, NP-NM = never planted and never mowed, previously farmed site, AP-NM = actively planted and never mowed, AP-M = actively planted and mowed). Letters indicate significance in the adult cohort (p=0.017). Bars indicate standard error.

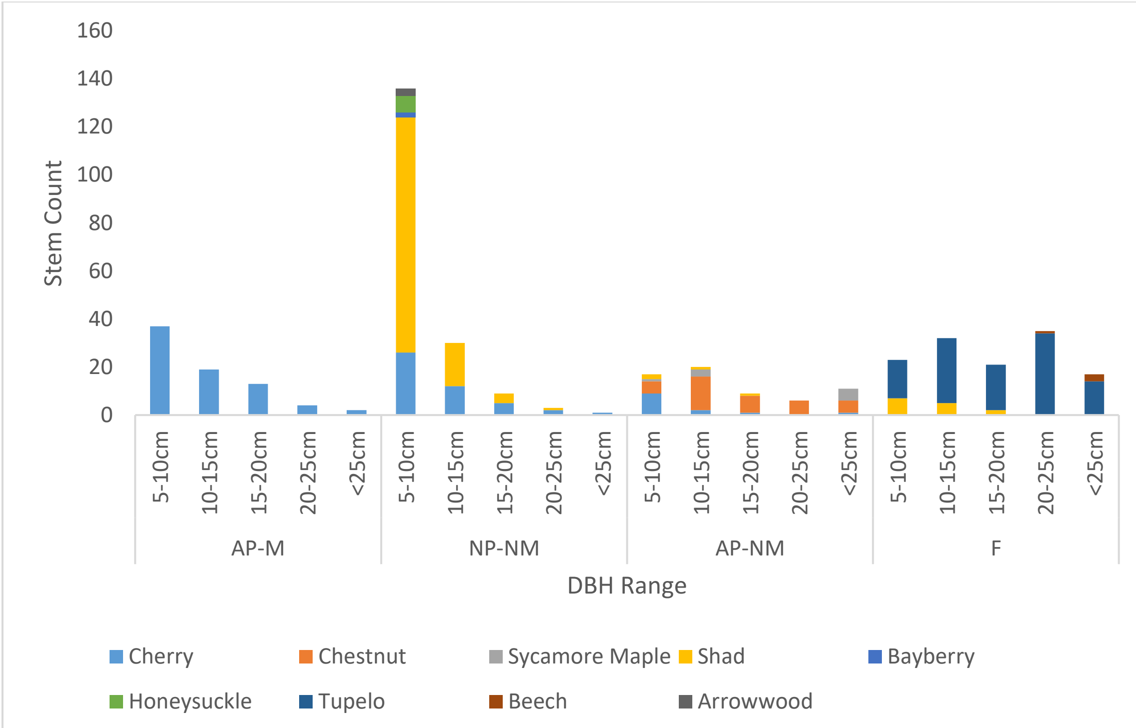

Figure 5- Size classes of adult trees (defined as >5cm DBH) counts by species

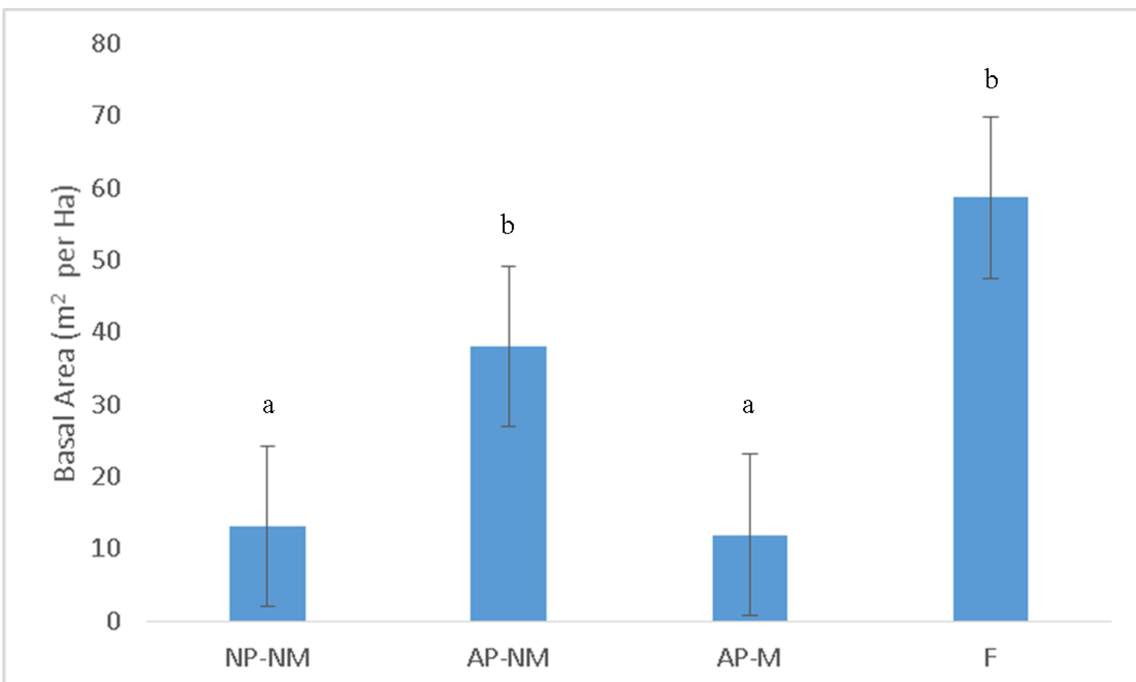

Figure 6- Basal area (m^2 per ha) for each treatment (F=forested never farmed treatment, NP-NM = Never planted and never mowed, previously farmed site, AP-NM = Actively Planted and Never Mowed, AP-M = Actively Planted and Mowed) (*p*=0.007) Shared letters indicate a lack of significant difference, error bars represent standard error.

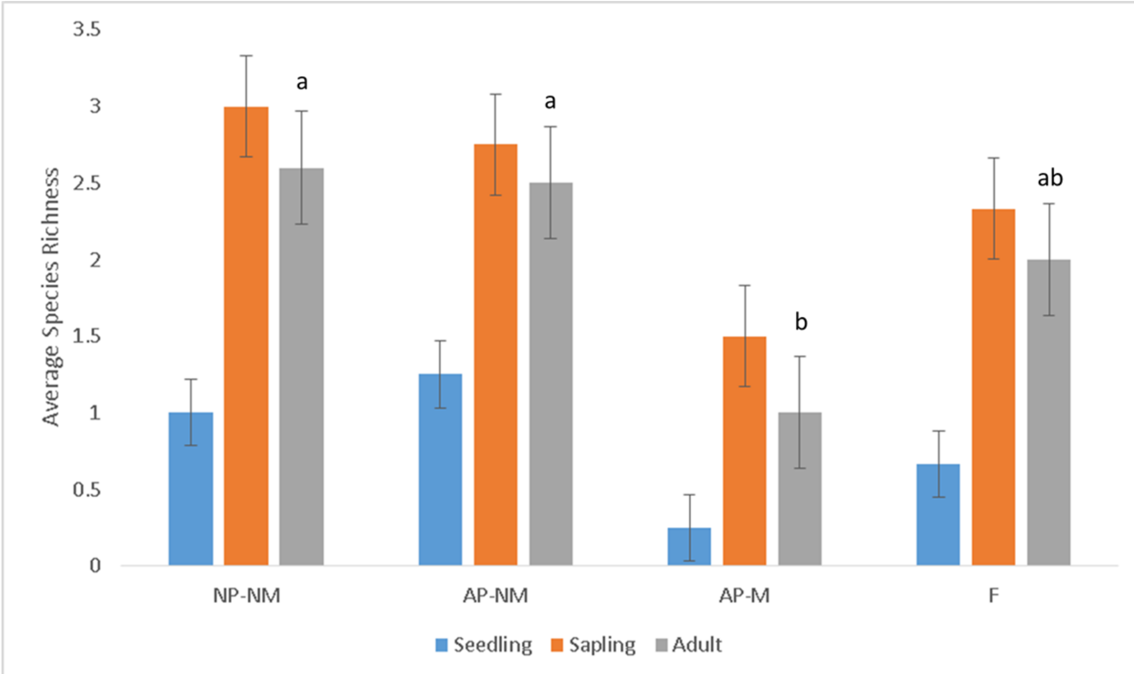

Figure 7- average number of species in each cohort (Seedlings with <1m in height, saplings with >1m in height and <5cm DBH, Adults with >5cm DBH) in each treatment (F=forested never, farmed treatment, NP-NM = never planted, never mowed, previously farmed site, AP-NM = actively planted, never mowed, AP-M = actively planted, mowed). Letters indicate significant differences between treatments in the adult cohort (a>b) while shared letters indicate a lack of significance.

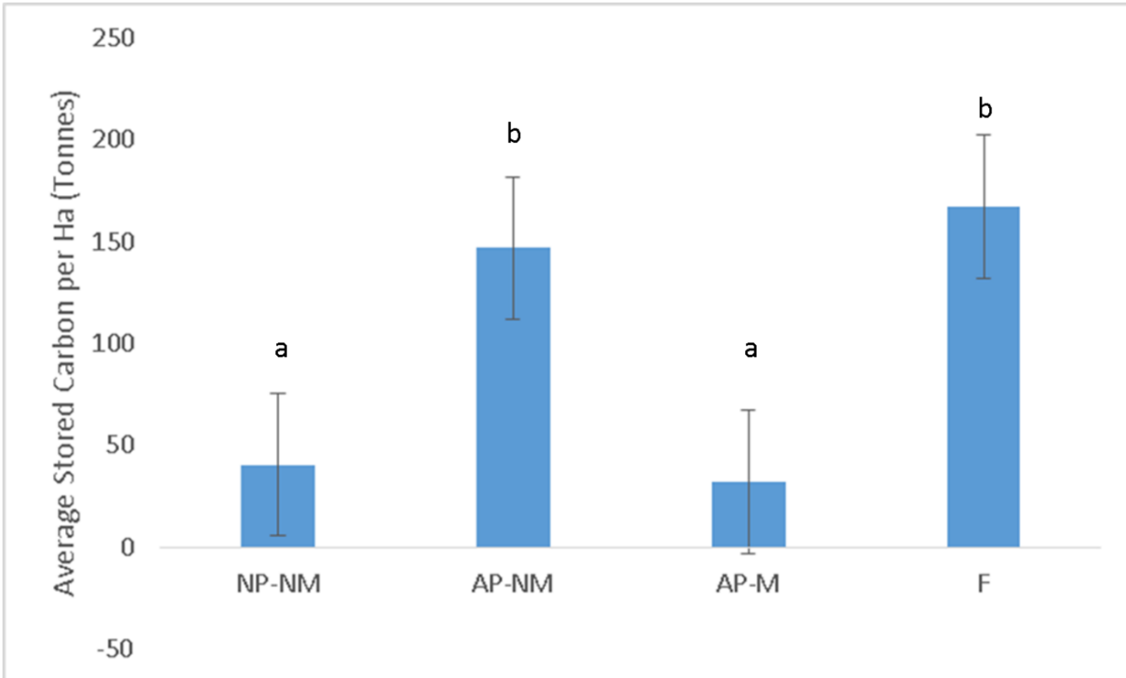

Figure 8- Average carbon stored (metric tons per Ha) in each treatment (F=forested never farmed treatment, NP-NM = Never planted and never mowed, previously farmed site, AP-NM = Actively Planted and Never Mowed, AP-M = Actively Planted and Mowed). Not found to be significant (p=0.17) Bars indicate standard error.

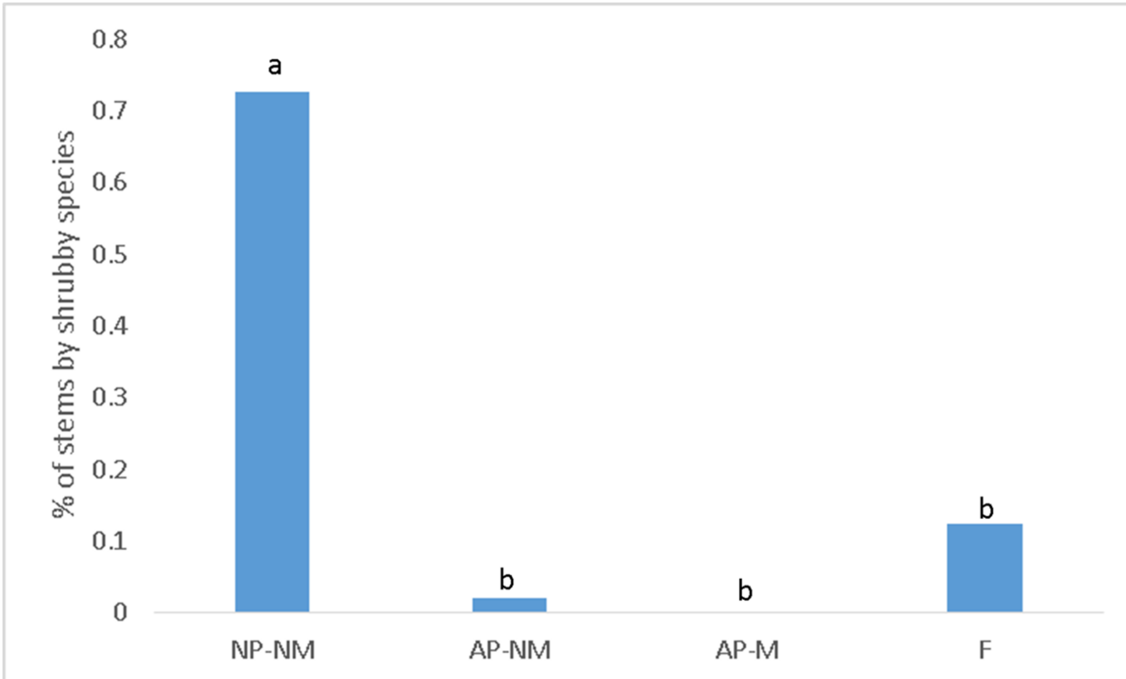

Figure 9- Percentage of each stems found to be shrubby species for each treatment (F=forested never farmed treatment, NP-NM = Never planted and never mowed, previously farmed site, AP-NM = Actively Planted and Never Mowed, AP-M = Actively Planted and Mowed) (p=0.00014). Shrubby species include *Amelanchier sp*., *Myrica sp*., *Vibernum sp.* and *Lonicera sp*. Shared letters represent a lack of significance.

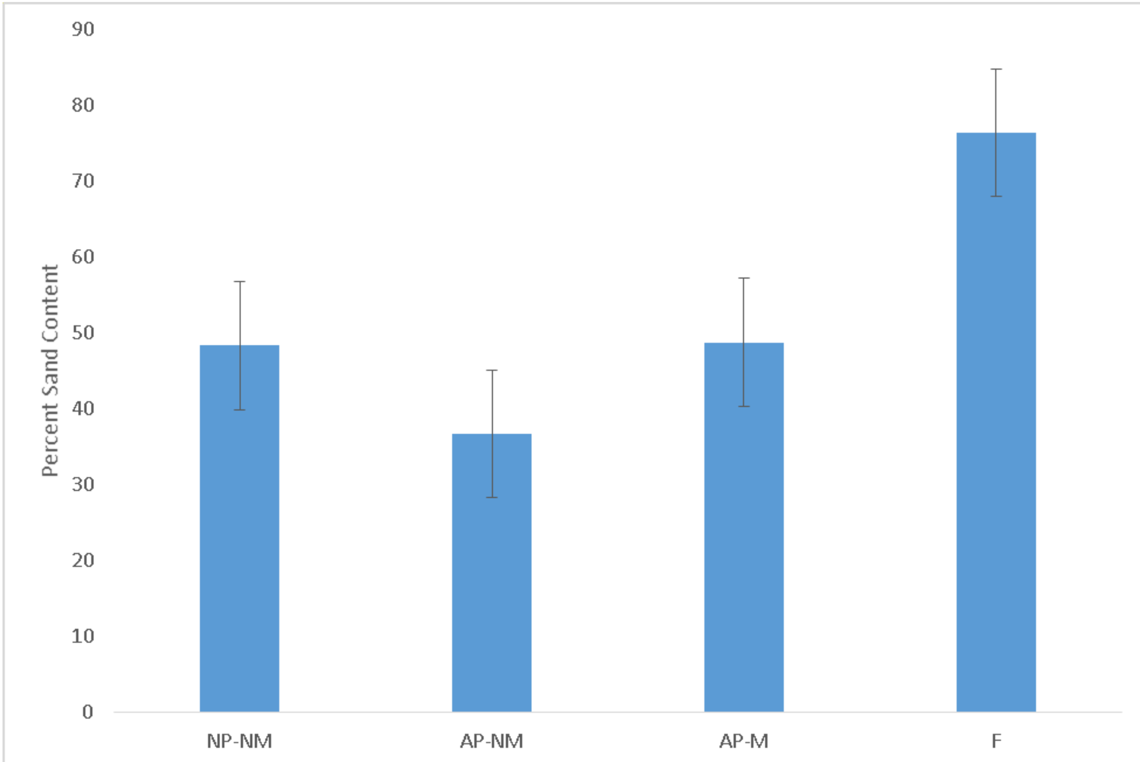

Figure 10-Average percent sand content found in each treatment (F=forested never farmed treatment, NP-NM = Never planted and never mowed, previously farmed site, AP-NM = Actively Planted and Never Mowed, AP-M = Actively Planted and Mowed). Error bars show standard error.

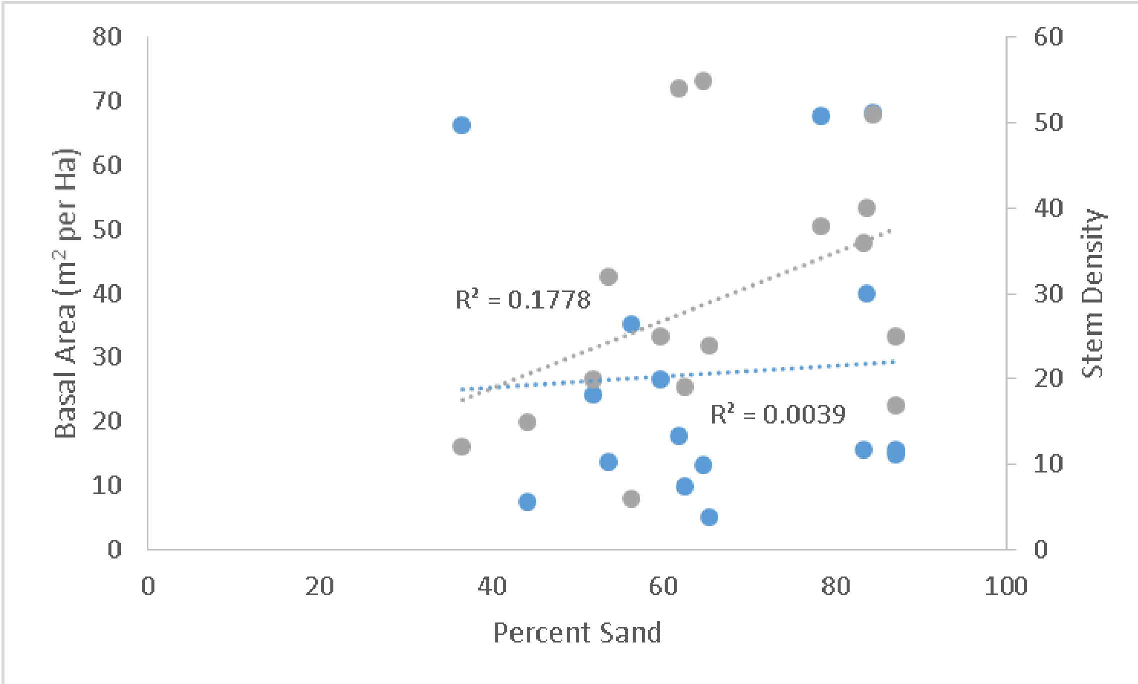

Figure 11- Relationship between basal area per ha (blue) and versus percent sand. (R^2=0.21,*p*=0.86), and Stem density per ha against present stand (in gray) (R^2=0.46,*p*=3.35).

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